A CONTRIBUTION TO PHASED ARRAY ULTRASONIC INSPECTION OF WELDS: DEFECT PATTERNS AND SIZING CAPABILITY

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Abstract

The paper presents defect patterns for weld inspection detected with phased array ultrasonic technology (PAUT). The sizing capability for length, height, outer and inner ligament for specific implanted weld defects in training samples and mock-ups with thickness between 6.4-52 mm. It is discussed the influence of beam angle on sizing the lack of fusion defect. More than 50 implanted weld defects with 70% crack population were sized using high-frequency (5-10 MHz) linear array probes. The correlation between the design/manufacturer flaw size and PAUT data for length, height and ligament is graphically presented. It was concluded the length is oversized by 2-6 mm, height and inner ligament are undersized by 0.2 to 0.5 mm, and outer ligament is oversized by 0.5 mm. The sizing results were based on non-amplitude techniques and pattern display of S- and B-scan. The sizing capability is far better than ASME XI tolerances for performance demonstration and comparable to time of flight diffraction (TOFD) ideal tolerances.

Introduction

The powerful information of sectorial scan (S-scan) in combination with focus beams and probe movement are currently used for a broad domain of weld inspection applications [1-8]. Recent validation techniques or inspection qualification [9-10] lead to a faster pace phased array application for weld inspection. It is quite obvious the new technology will get a solid ground into the weld inspection, namely for the following reasons:

- Is a pulse-echo technique
- Has a direct link between S-scan and the welded component
- Increase productivity and reliability
- Could be applied for welded components with complex geometry, limited access or dissimilar metal welds
- Regulators and standardization organizations encourage the technology transfer and procedure qualification based on phased array ultrasonic technology
- Standardization process is well under way [4, 11]

The paper presents the preliminary results performed on welded samples with implanted defects and on piping mock-ups used for technician training. The following aspects will be addressed:

- Is any weld defect pattern (image) provided by PAUT, similar with radiographic film?
- is any link between S-scan image and defect location in the test piece?
- what is the PAUT sizing capability for the implanted defects (length, height and ligament)?

The presented paper is short version of the paper presented in three parts in CINDE Journal in 2007-2008 [12]. The 3-part paper is also presented in On-line Journal ndt.net [12]. Examples of 2-D and 3-D data plotting of weld defects may be found in ref. 13.

PAUT Patterns for Weld Defects

A large variety of defects were detected and data presented in 2-D layouts. The weld patterns are presented with explanation in **Figure 1** to **Figure 6**.

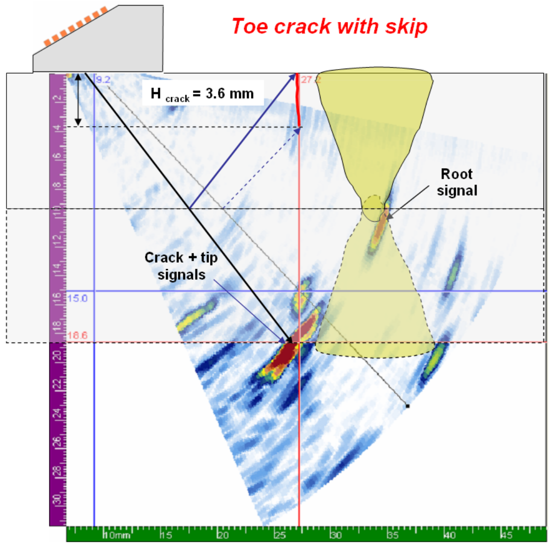

Figure 1: 2-D data plotting of a S-scan image in detecting and sizing a toe crack. Detection was performed with skip. The crack height is measured from corner trap to the last diffracted signal of crack tip. Actual crack height is 3.8 mm.

Figure 2 presents the detection, location and sizing of a side-wall lack of fusion located at 1.5 mm (almost at inner surface) versus the weld root. A combination of B- and S-scan is providing the LOF length, height and inner ligament. Note the root signal shadowed by LOF location.

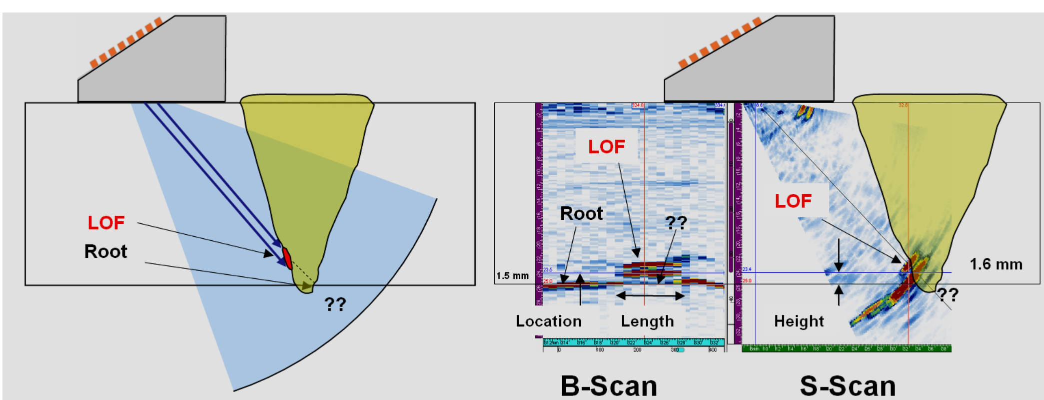

Figure 2: 2-D data plotting for a LOF located near the inner surface. A combination of B-and S-views provide the LOF parameters (location, length, height, orientation). *Left:* detection principle and shadowing effect of the root signal; *right*: 2-D data plotting for S-scan; B-scan was added for length and inner ligament measurements.

Figure 3 represents 2-D data plotting for a side-wall LOF detected with skip.

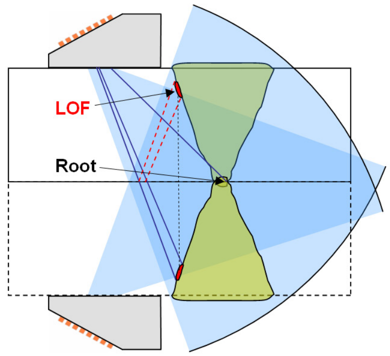

Figure 3: *Left:* Detection principle and data plotting in S-scan for a side-wall LOF detecting with skip; *Right:* S-scan data plotted over weld overlay.

Figure 4 presents a group of pores located at 1.5 mm from the outer surface detected in ½ skip. Porosity nest dimensions are: 1.5 mm x 3 mm x 10 mm (length-evaluated in B-scan).

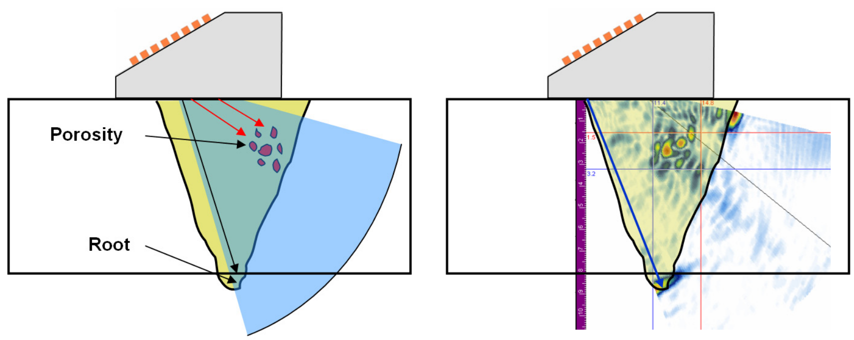

Figure 4: S-scan data plotting for porosity detected in ½ skip. *Left:* principle; *right:* S-scan data over 2-D weld overlay.

Figure 5 illustrates the data plotting for an underbead crack in T-weld. Height is measured with index cursors and the inner ligament with ultrasonic (depth) cursors.

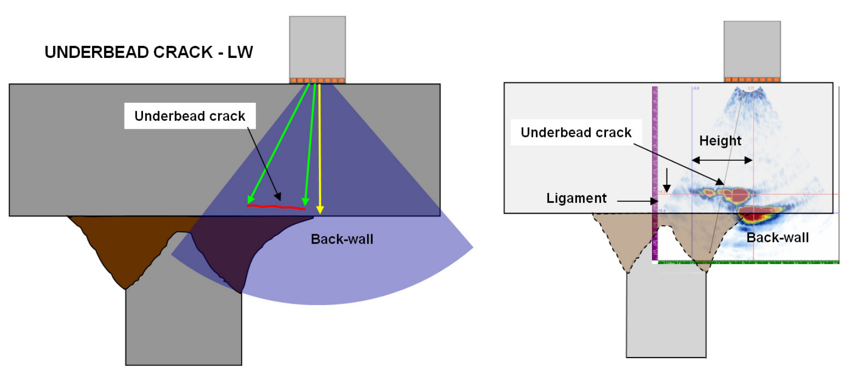

Figure 5: Principle of detection (*left*) and S-scan data plotting for an underbead crack located in a T-weld.

A toe crack and a lack of fusion in T-weld detected by skip are presented in **Figure 6.**

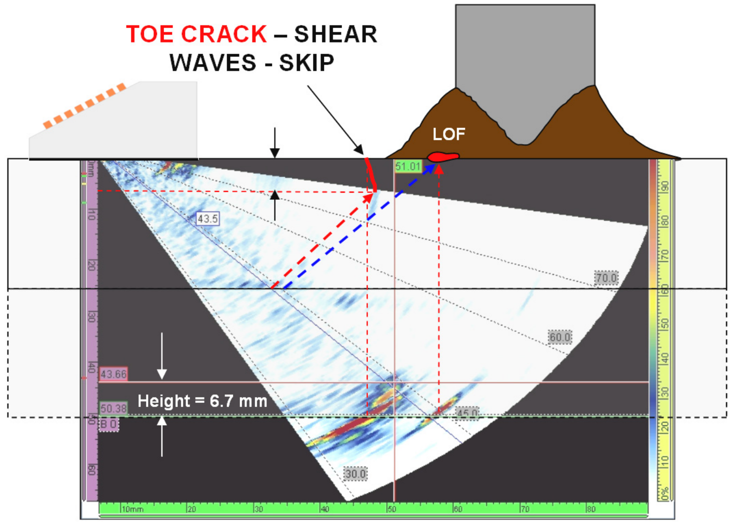

Figure 6: Example of toe crack and LOF detection and plotting using the skip. Omniscan data crack height is 6.7 mm vs. 6.8 mm actual height.

Sizing Accuracy

The thickness of welded samples used in this program was between 6.4 – 52 mm. Four mock-ups were pipe-to-pipe butt welds. More than 50 implanted defects were detected and sized in 25 samples. **Table 1** presents an example of the variety of samples and flaw type.

Table 1: Test pieces with implanted defects used for sizing capability study (examples).

Test piece ID	Thickness [mm]	Defect type	Length x height [mm]	Ligament [outer/inner- mm]
UT-1311	9.5	Porosity / slag	13 x 2.4	1.5
UT-1313	16	LOF	12 x 3.2	3.2
UT-1315	9.5	LOF	8 x 3.8	2.2
		Toe crack	13 x 3.8	outer
UT-1316	16	crack	13 x 3.8	inner
		slag	20 x 3.8	1.5
TP 9	365 x 24	flaw 3-crack	35 x 8	inner
		flaw 4-LOF	25 X 3	5.2
		flaw 5-LOF	30 X 3	2.4
		flaw 6-crack center line	45 x 12	2
		flaw 7-crack	35 x 10	inner
BLOCK 6	204 x 12.7	flaw A-crack	40 x 9.2	inner
		flaw E-crack	15 x 2.5	inner
OH 0010	25	Crack-HAZ	13 x 5	inner
		LOF	23 x 2.5	3.2

The probes used in this experiment are presented in **Table 2**.

Table 2: 1-D linear array probes used for sizing

Probe ID	F [MHz]	Nr. Elem.	Pitch [mm]	Remarks
9+45T	6	32	0.55	Shear waves
32+45T	5	20	0.45	Shear waves; CS-SS welds
66+45T	6	25	0.4	Shear waves
43+45T	8	16	0.6	Shear waves CS samples
2	10	20	0.31	L-waves CS
9	6	32	0.55	L-waves CS-SS
22	7	32	0.44	L-waves
23	7	20	0.4	L-waves
38	8	25	0.4	L-waves
42	7	32	0.5	L-waves

OMNISCAN MX was used as a phased array machine in combination with pipe scanners and with X-Y lab scanners (see **Figure 7**). Data were collected at 0.5 mm encoder increment along the weld length.

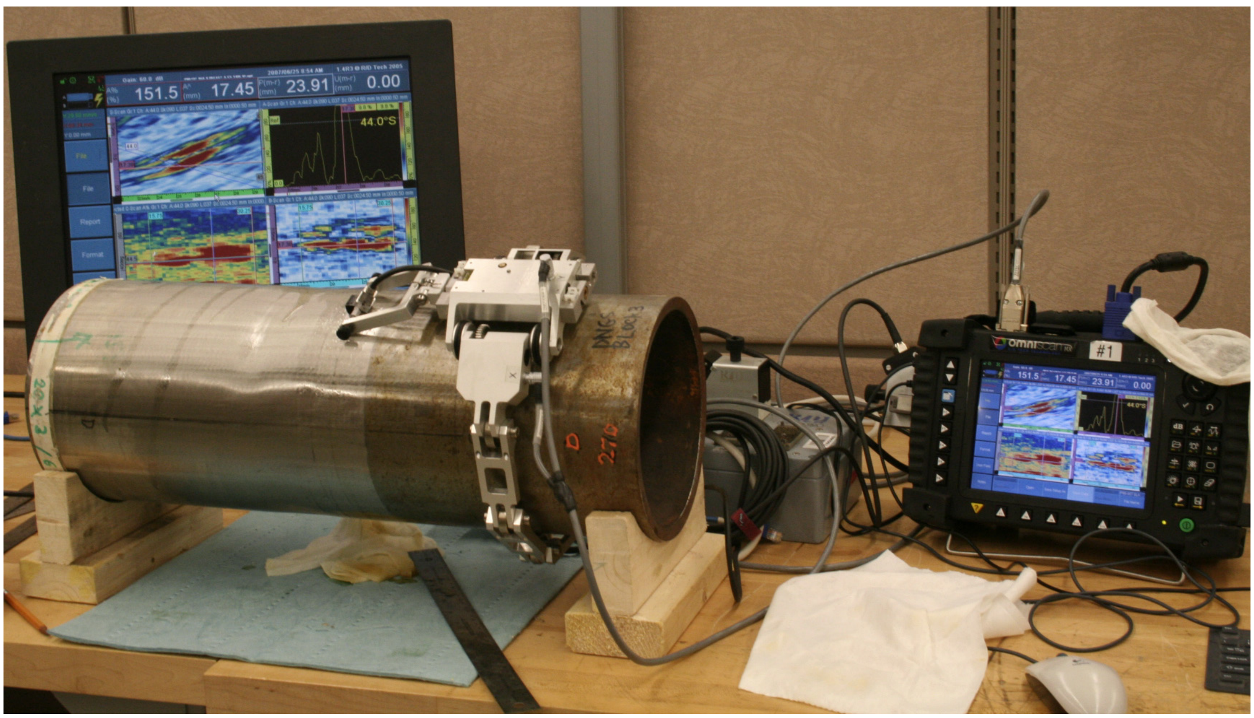

Figure 7: Example of experimental set-up for sizing capability on dissimilar piping weld mock-up DNGS BLOCK #3.

Sizing capability was performed for height, length and ligament (inner and outer).

The flaw ***length*** is oversized by 2 mm (see **Figure 8**). Some flaws were oversized by 3 to 6 mm. Implanted defects presented satellites defects, which may affect the designed flaw length and height. The length accuracy provided by PAUT is on order of magnitude less than AMSE XI acceptance tolerance for performance demonstration (RMS $_{\text{Length ASME XI}}$ = ± 19 mm) (ref.14).

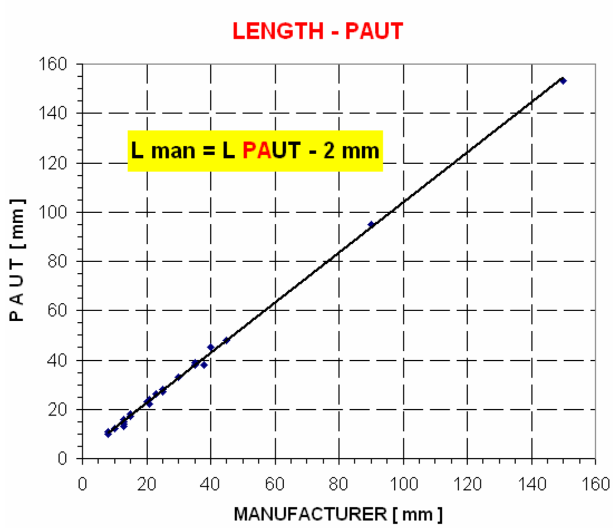

Figure 8: Correlation between manufacturer and PAUT for flaw length.

The flaw ***height*** measured by PAUT has an under-sizing trend of 0.2 to 0.5 mm (see **Figure 9**).

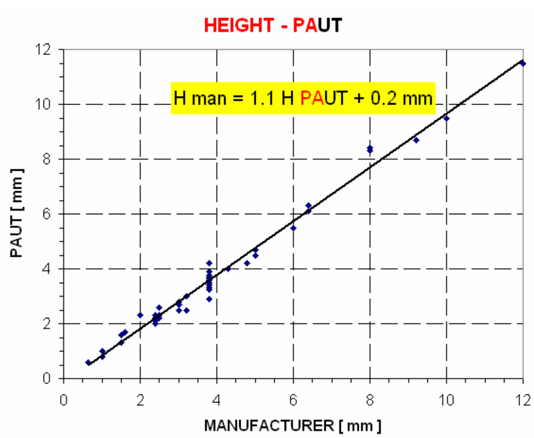

Figure 9: Correlation between manufacturer and PAUT for flaw height.

The height error evaluated by PAUT is an order of magnitude less than the ASME XI tolerances for performance demonstration ($RMS_{\text{height ASME XI}} = \pm 3.2$ mm).

The flaw ***ligament*** was evaluated for different probe index positions, depending on weld crown status (as welded, flush, overlaid). **Figure 10** presents some examples of ligament measurement for different weld flaws (cracks, LOF, slag/porosity).

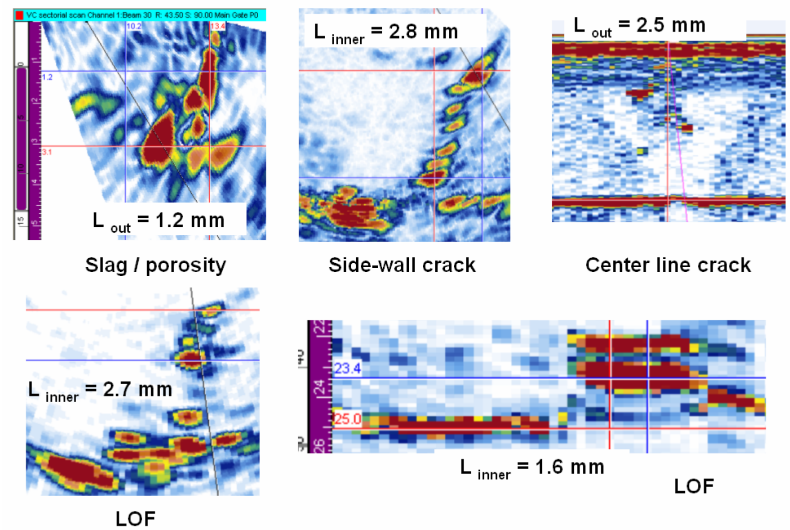

Figure 10: Examples of ligament measurement for different weld flaws.

The over-all PAUT performance for ligament evaluation is presented in **Figure 11**.

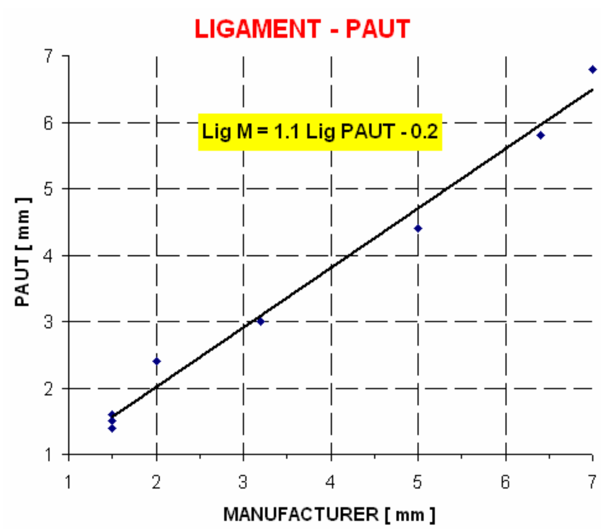

Figure 11: Correlation between manufacturer and PAUT for flaw ligament evaluation.

Concluding Remarks

Weld defects presents an image-based pattern in S-scan, which is easy to explain and plot into 2-D layout of weld.

The sizing capability using PAUT may be concluded:

- Length is ***oversized*** by 2 to 6 mm;
- Height is ***undersized*** by 0.2 to 0.5 mm
- Ligament is ***oversized*** by 0.3-0.6 mm
- Flaws with ***ligament > 1.5 mm*** are correctly called as embedded. A combination S-B-scan is required to avoid the false calls in the root area.

Acknowledgements: The author wishes to thank OPG - IMCS Management for granting the publication and presentation to the 8th International Conference on CANDU Maintenance of the present paper.

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